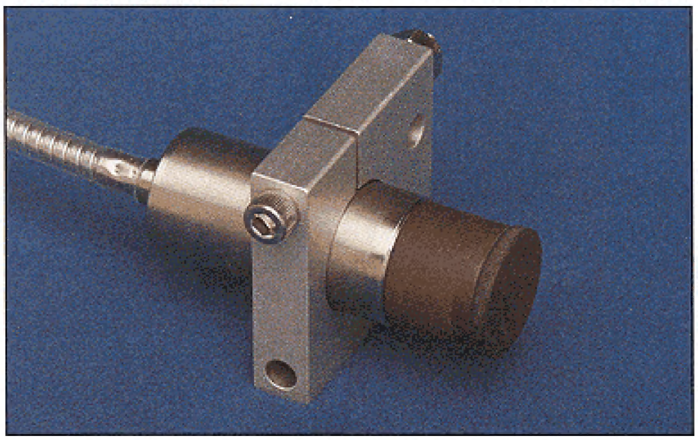
Back-to-Basics

Part three

Transducer and monitoring system recommendations for specific machine types...

Centrifugal compressors



This article is the third of a series of three. Previous articles (*Orbit* September 1989 and December 1989) have been published on the subjects of transducer operation and selection. This article is the first of several which will cover a specific machine type and the Bently Nevada recommendations for transducer and monitoring systems required for basic machine protection. These, and other related publications, are available from your nearest Bently Nevada representative.

The recommendations given here represent the ***minimum*** system requirements for machinery monitoring purposes, for basic protection against the most common problems associated with centrifugal compressors. Some generalizations will be made in this article, and as such, there will be some exceptions to the recommendations provided here. Exceptions could be based on a specific machine design, type of service and process conditions, machine maintenance history, etc.

The following discussion and recommendations apply to centrifugal compressors with one or more stages, fluid film radial bearings, and impellers either mounted between bearings or overhung. For this type of machine, the two most commonly occurring problems are rotor unbalance and misalignment. Other problems that occur less often include rubs (shaft to bearing or seal), coupling problems, shaft/bearing (or seal) instabilities, shaft bow and loose rotating parts. All the above problems are rotor-related and produce an increase, or at least a change, in shaft radial vibration relative to the bearing(s).

Less frequent are structural related problems such as loose bearing housings, soft feet, foundation warpage or deterioration, and piping vibration or strain. These problems, when they do occur, cause a change in structural vibration of the offending component, sometimes along with a change in shaft vibration relative to the bearing(s). For most machine designs, shaft vibration motion is not transmitted to the bearing housings or machine structure to any significant degree.

Therefore, shaft radial vibration and position measurements are the best measurements for basic machine protection against the most common machinery problems. Such measurements are provided by shaft observing noncontactingproximity probes. The probes are installed through the bearing housing or attached to a direct support member. Thus, the measurement is of shaft vibration and position relative to the bearing(s).

Different problems can occur that affect the behavior of the rotor in the axial direction. These include excessive axial load, balance piston wear or failure, and compressor surge. The recommended protection against these problems is the installation of proximity probes measuring the shaft position and vibration in the axial direction.

Radial vibration

For each radial bearing, two proximity probes should be installed orthogonally (XY or 90 degrees apart). XY measure-

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ments are required because shaft vibration, under both normal and machine malfunction conditions, usually is not unidirectional. Shaft centerline dynamic motion (vibration Orbit) is typically elliptical, and therefore must be measured in two planes (XY).

One of the most common problems, rotor unbalance, produces shaft Orbits that are usually slightly elliptical. Another common problem, misalignment, tends to produce shaft motion that is even more elliptical. Severe misalignment produces other dynamic patterns such as the classical "banana" and "figure eight" shapes. Even when shaft motion *is* predominantly in one radial direction, that specific direction cannot be predetermined. For example, the orientation of the major axis of an elliptical Orbit is dependent upon the direction of the misalignment. Since on most machines, the direction of misalignment is not predictable, neither is the direction of the largest radial vibration amplitude. Thus, the two most common machine problems require XY probes for machine protection.

Each pair of XY proximity probes should be connected to a dual channel (XY) vibration monitor. This monitor should be specified with various options appropriate for the machine. The full-scale meter range should be small enough so that vibration under "normal" machine conditions will produce readings at least greater than ten percent (10%) of full scale and large enough so that the Danger (machine shutdown) setpoint is no more than ninety percent (90%) of full scale.

The vibration monitor should have an amplitude detection circuit that evaluates the overall (unfiltered) vibration signal and measures the ***true peak-to-peak*** signal amplitude. For shaft relative vibration measurements, peak-to-peak amplitude represents the total displacement motion of the shaft relative to the bearing clearance. Since the bearing diametral clearance is known, the peak-to-peak shaft relative displacement amplitude can be compared to this clearance, yielding an evaluation of the parameter ***clearance absorption***. This is the percentage of the total bearing clearance that is occupied by shaft vibration. Some users establish a general rule that shaft relative vibration amplitude should not exceed one-half of the bearing diametral clearance.

Other amplitude detection techniques, such as s_{max} and RMS, are not recommended. RMS is an averaging technique, and we believe that no averaging should take place on this signal. Any averaging will mask the true extremes of shaft motion within the bearing and will sacrifice the valuable information of clearance absorption. S_{max} is an attempt to determine the maximum shaft displacement, even when the direction of maximum shaft motion is exactly between the two measurement planes (a 45° flat orbit). There is a possible error if only peak-to-peak amplitude is measured individually for each of the two probe channels. The maximum error in this situation is about 30 degrees. However, there is greater potential error using the mathematical calculation normally proposed by s_{max} advocates, and this error easily can exceed 30 degrees. For further information on this subject, refer to our Applications Note on the subject of vibration amplitude detection.

Voting logic is not recommended for XY radial vibration monitors. The purpose of most voting logic schemes is to prevent a single transducer failure from causing a false monitor alarm (or worse, a false machine shutdown). In the case of radial vibration monitoring with proximity probes, the most common transducer failure modes result in the complete loss of the transducer's dynamic (vibration) signal. Typically, upon transducer failure, the vibration monitor simply indicates zero vibration, and thus no monitor alarms. Even the odd problem of an intermittent failure (e.g., an intermittent short or an open circuit), is accurately detected as a transducer problem, not real machinery vibration, with Bently Nevada's proprietary Timed OK Channel Defeat circuit. This circuit is standard in all monitors of the 3300 System and is designed to inhibit the Danger alarms for that monitor if a transducer problem is detected.

The other reason voting logic is not recommended for this application is the result of a false assumption. Two out of two voting logic systems for radial vibration assume that when a machine problem occurs, both probes will measure high vibration. That assumption is simply ***not valid***. Many machine malfunctions can produce shaft relative vibration primarily in one direction with an Orbit that is highly elliptical. If the shaft motion is predominantly in the direction of one of the probes, then the voting logic function would not allow the Danger relay to actuate. Therefore, there is a danger in using a dual voting logic scheme for XY radial vibration probes.

A voting logic scheme for XY shaft vibration monitoring would seem reasonable if the probability of a false mon- ▶

itor alarm were equal to, or higher than, the probability of highly elliptical shaft Orbits. In fact, in part due to our excellent monitor design, false alarms on Bently Nevada vibration monitors are a rare occurrence. On the other hand, machines with elliptically shaped Orbits are a very common occurrence. In our experience, elliptical Orbits occur much more frequently than do false vibration monitor alarms due to transducer problems.

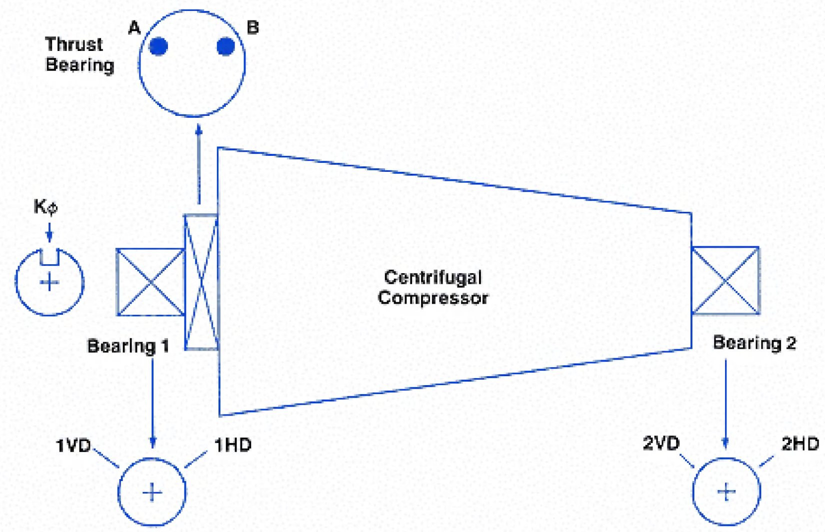

Figure 1
Typical machine case layout

Radial position

The *first* result of misalignment, one of the most common problems on centrifugal compressors, is usually a change in the shaft average centerline radial position within the bearing clearance. This change occurs often *before* any measurable change in the vibration characteristics of the machine. Other problems, such as bearing wear, coupling lock-up, etc., also result in a change in shaft centerline position.

The same pair of XY proximity probes installed for measuring radial vibration also can be used to indicate shaft radial position. While the *dynamic* transducer output signal is used to measure radial vibration, the evaluation of radial shaft position is made by using the *simultaneous dc* (average gap) signal output. Because proximity probes provide a relative measurement, this dc output can be used to determine the average radial shaft centerline position relative to the bearing clearance.

In order to provide early warning of a change in machine condition, the standard Bently Nevada two channel radial vibration monitor provides alarm setpoints that actuate on a change in the proximity probe dc voltage signal. Thus, alarm setpoints can be chosen based on the "normal" average position of the shaft and the acceptable limits of shaft position (obviously, at or within the bearing clearance limits).

Bearing housing vibration

It is normally unnecessary to consider bearing housing (seismic) vibration measurement on centrifugal compressors. Most machine designs are such that little of the shaft vibration energy is transmitted to the bearing housing or machine casing due to the relatively high bearing support stiffness and/or high machine case to rotor mass ratio. For this reason, velocity transducers and accelerometers should never be used *in place of* proximity probes for basic protection on these type machines. Only when a significant amount of shaft vibration is transmitted to the bearing housing should seismic transducers be used, and then they should be used *in addition to* proximity probes.

Axial position

While several common machine problems cause a change in shaft *radial* vibration and/or position, several other problems are also common failure mechanisms and cause a change in shaft *axial* position and/or vibration. These problems include excessive axial load (due to balance piston failure, erosion or fouling of rotating elements, etc.), thrust bearing lubrication failure, compressor surge, and abnormal shaft axial position or vibration (due to coupling lock-up, coupling axial resonance, etc.).

The monitoring system required to detect the above types of problems includes proximity probes installed to observe the shaft's thrust collar or other axial surface on the shaft. These are standard proximity probes that measure both shaft axial position and vibration. For axial position measurement, the probes are connected to a thrust position monitor. This monitor evaluates the dc gap output of the proximity transducer system and provides alarm setpoints to warn of excessive shaft position changes in either direction on the machine (active or inactive, toward or away from the probes).

Two probes are recommended, installed in a redundant manner. That is, both probes should observe, as closely as possible, the same integral surface on the shaft. Both probes should be connected to the same monitor with two out of two voting logic. Voting logic is recommended because the most common types of transducer failures can produce a full-scale false reading, thus producing a false alarm (or false machine shutdown). The monitor should be specified with various options appropriate for the machine. The full scale meter range should be large enough so that the Danger (machine shutdown) setpoint is no

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more than ninety percent (90%) of full-scale in either direction.

We do ***not*** recommend the use of voting logic between shaft axial position and thrust bearing temperature measurements. There are some situations where thrust bearing failure can occur without high thrust bearing temperature. Examples include electrostatic discharge which removes thrust bearing material, defective or overloaded bearing which removes thrust bearing material, and the situation of a loose thrust collar. In these cases, if "yes" voting between bearing temperature and shaft position must occur before a Danger alarm is actuated, then the temperature measurements may miss a valid Danger alarm condition and cause severe machine damage.

Axial vibration

Very few machinery problems produce shaft axial vibration as the primary indicator of the problem. For example, in some cases misalignment can produce axial vibration, but the first indicators of a change in shaft alignment are usually a change in shaft ***radial position*** and/or a change in shaft ***radial vibration***. Since axial vibration is not the primary indicator of any common machine malfunctions, we do not recommend that axial vibration be a continuously monitored parameter. However, since axial probes will be installed for axial position monitoring, the dynamic transducer signal is available on the monitor front panel for periodic connection of diagnostic instruments.

Keyphasor®

A Keyphasor® transducer is a proximity probe that observes a radial shaft surface that contains a once-per-turn discontinuity. This transducer thus produces a voltage pulse with every shaft rotation. This pulse can be used as an input to a tachometer to measure shaft rotative speed and also can be used as a timing pulse for measuring vibration phase lag angle. Phase angle data is extremely valuable as a diagnostic tool for trouble-shooting rotor unbalance, misalignment, bearing instability, shaft cracks, critical speed resonances and other common problems.

Our normal recommendation is to install the Keyphasor® probe on the driver of the machine train. In the case of a centrifugal compressor, this would be the turbine or electric motor. For a direct coupled machine train (no gearboxes, fluid couplings, etc.), a Keyphasor® on the driver can be used either when the machine train is run coupled or when the driver is run solo. If the Keyphasor® is installed on the compressor, it becomes useless for solo driver run data.

A Keyphasor® is recommended on a compressor in only one of two situations. If there is a speed-changing element (gearbox, etc.) between the driver and the compressor, a Keyphasor® should be installed for each different shaft speed. If it is not possible at the time of installation to install a Keyphasor® on the driver, one installed on the compressor is better than no Keyphasor® at all.

System layout

Figure 1 is a typical machine case layout drawing showing the radial and axial transducers as specified in the above system. A drawing of this type should be a permanent part of a machine's historical documentation. Not only are transducer locations shown, but their angular orientations are shown as well. As you can see, both pairs of XY probes should be installed at the same angular orientations at each end of the machine.

Industry standards

The recommendations given here describe a system that meets the requirements of several industrial standards for machinery monitoring. Among these are the International Standards Organization (ISO 7919), Verein Deutscher Ingenieure (VDI 2059) and the American Petroleum Institute (API 670). The only additional requirement for API 670 is the installation of monitoring for radial and thrust bearing metal temperatures. We also support this recommendation. Bearing temperature data can be valuable for correlation with shaft vibration and position data. According to API 670, one or two sensors (depending on the bearing length to diameter ratio) should be installed in each radial bearing and two sensors should be installed on each side of the thrust bearing.

Machinery diagnostics

This article outlines the minimum equipment recommended for a basic machine protection system. With the system described, a user will have the information required to detect the most commonly occurring machine malfunctions on most types of centrifugal compressors. Once a problem is detected, the next logical step is machinery diagnostics to determine the source and nature of the problem. The monitors installed for machine protection simply provide alarms when measured values exceed setpoints. Typically, no machinery diagnostic information is provided by standard systems. But, the system described ▶

above includes the best possible start toward meaningful machinery diagnostic information. That start is the installed transducers, proximity probes for radial and axial measurements.

Not only are proximity probes the best transducers for basic machine protection on centrifugal compressors; they also are the best transducers for machinery diagnostics. Especially when used with a Keyphasor® signal, shaft relative vibration and position data can clearly identify all common machinery malfunctions. For complete machinery diagnostics, in addition to the transducers specified, analytical instruments should provide the measurements of vibration phase angle (1X amplitude and phase, 2X, etc.), shaft attitude angle and eccentricity ratio, vibration shape and form, direction of shaft precession and vibration frequency.

When performing machinery diagnostics, it often becomes necessary to evaluate the machine's vibration response to rotor balance resonances (critical speeds) and to determine rotor mode shapes. For this analysis, having only one pair of XY probes at each end of the shaft may not be sufficient for a thorough investigation. Additional radial XY probes, installed longitudinally away from the machine protection probes inboard and/or outboard of the radial bearings, can provide a wealth of diagnostic information. These probes are called ***Mode Identification probes*** and should be installed at the same radial angular orientation as the machine protection probes.

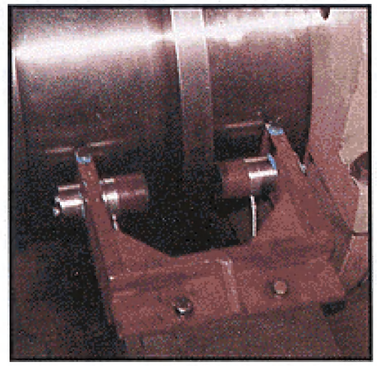
References

For further information on the monitoring and analysis of rotating machinery, refer to other Bently Nevada ***Orbit*** articles and Applications Notes. Related subjects include the use of Mode Identification probes, voting logic systems, and recommendations for transducer and monitor systems for other types of rotating and reciprocating machinery. These articles can be obtained from your nearest Bently Nevada representative.

ProbeTip

Fabricating a mounting bracket

During a recent Turbine Supervisory Instrumentation installation, a Bently Nevada Product Service representative was faced with a difficult mounting configuration. Due to the large amount of rotor growth expected, two 50 mm nonthreaded side exit probes were required to view a three inch collar on the Low Pressure (LP) end of a 500 MW turbine/generator. This layout was designed to obtain a complimentary differential expansion measurement. Setting the gap of the probes by means of shims was not practical in this application. Instead, a smooth body extension was designed which could be bolted onto the back of the 50 mm probes to allow the probes to slide back and forth for proper adjustment. A bracket designed with a built-in mounting clamp was used to hold the probes in place. (See Figure 1 for details.)



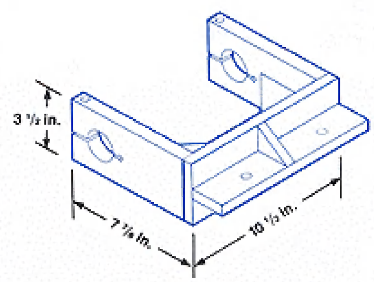


Figure 1

This design allows you to obtain Proximitor® calibration curves with the 50 mm probes viewing the actual LP collar as the target. The 50 mm probes were physically gapped in increments of .025 inch (.635 mm) using parallels. The probe was locked in place using the bracket before a corresponding dc voltage output was documented. Since the Proximitor® curves were obtained with the probes in their actual mounting location, outside factors could not cause an error when gapping the probes to their cold gap setting.

The customer was concerned about the accuracy of using two probes for a single measurement. At the same time, he was uncertain of the function of the crossover voltage as it pertains to the LP complimentary input differential expansion monitor. Using this bracket design, the Product Service representative demonstrated the monitor's operation by physically sliding the bracket into the machine, thereby simulating rotor growth. This demonstration indicated there was no error in the measurement.